Gallium Nitride & Related Wide Bandgap Materials and Devices

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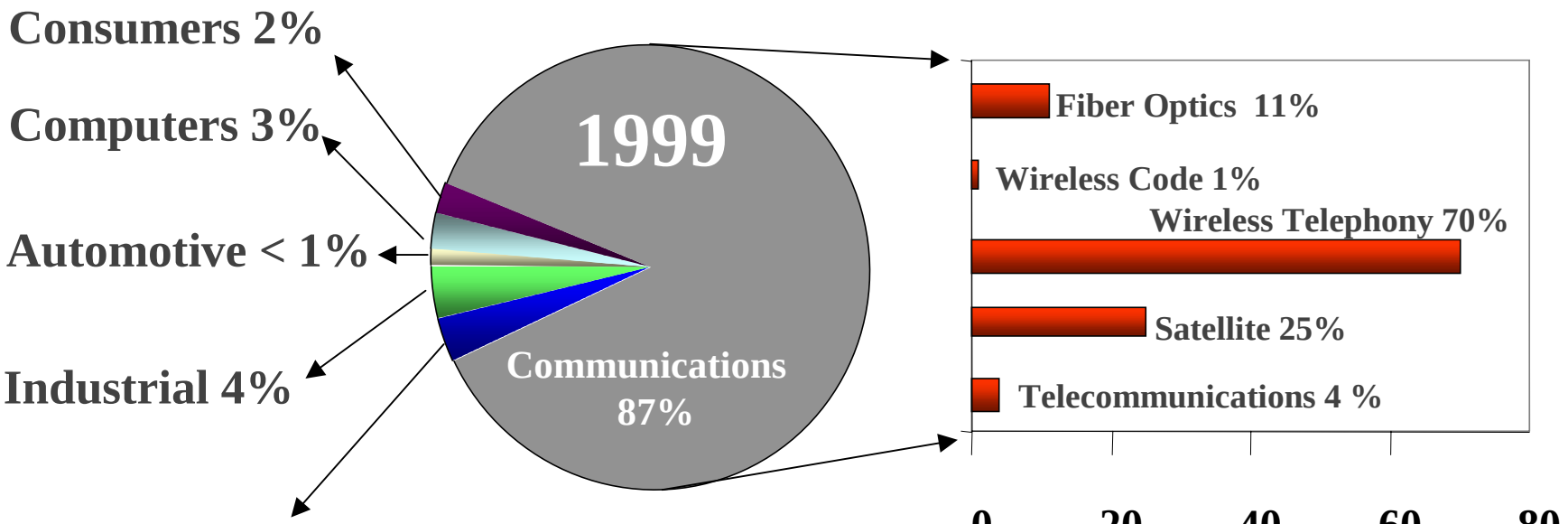
DARPATech 2000

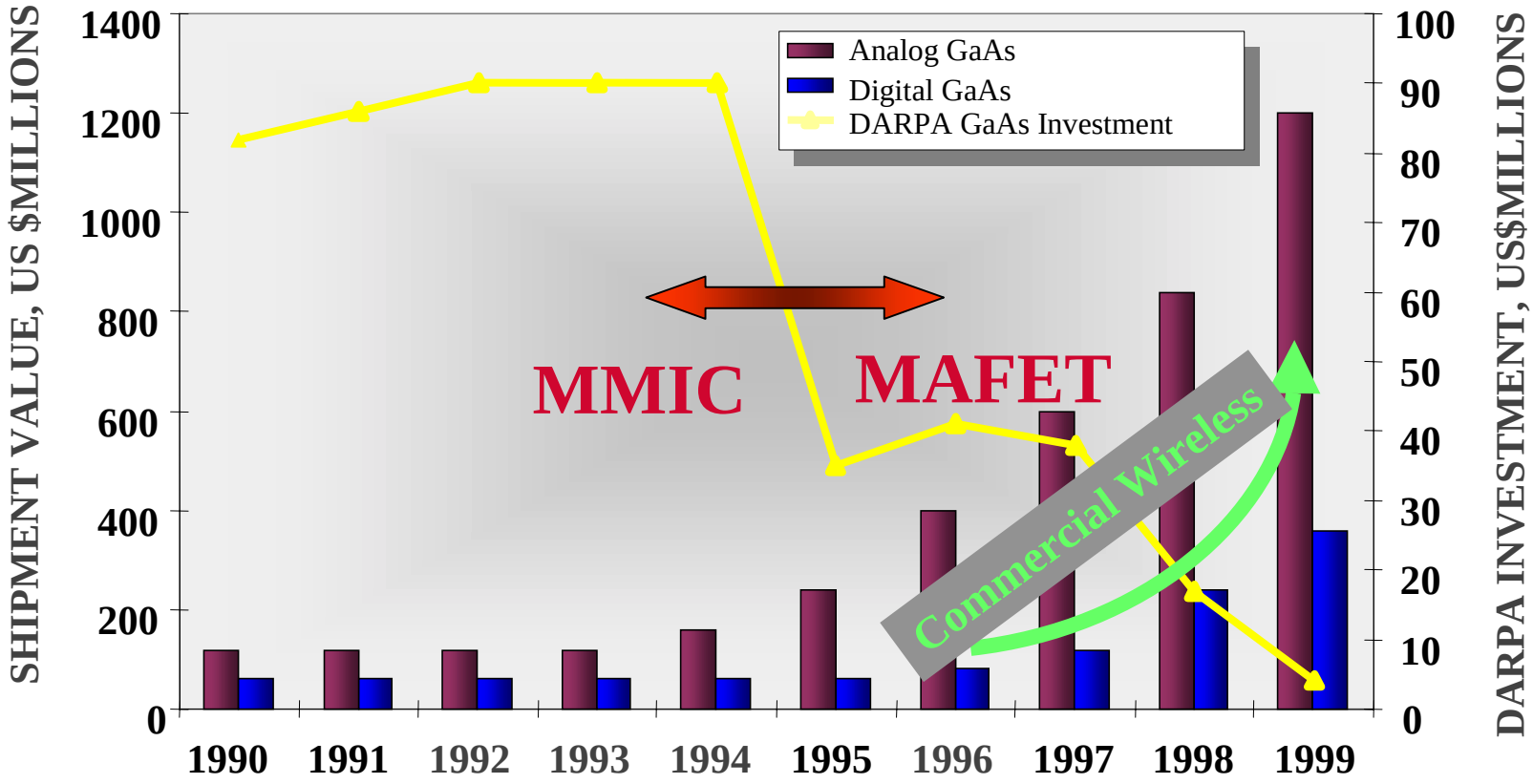
GaAs IC Markets

1999 Market $11 Billion
2005 Market $20 Billion



Military 3%
($330M/year)

GaAs IC Market 1990-1999



Yesterday's military challenges became today's commercial reality

Unmet Challenges in RF Analog Front Ends

- Power Density > 1 W/mm
- Multi-octave Bandwidth
- High Efficiency > 50%
- Linearity
- Low Noise Figures
- Low Phase Noise

X Band

Ka Band

V Band

W Band

Future DARPA Focus

Electronic Properties of Semiconductor Materials

	Si (----)	GaAs (AlGaAs/ InGaAs)	InP (InAlAs/ InGaAs)	4H SiC (----)	GaN (AlGaN/ GaN)
Bandgap (eV)	1.1	1.42	1.35	3.26	3.49
Electron mobility (cm^2/Vs)	1500	8500	10000	700	900
Saturated (peak) electron velocity ($x10^7$ cm/s)	1	2.1	2.3	2	2.7
2DEG sheet electron density (cm^{-2})	NA	$<4 \times 10^{12}$	$<4 \times 10^{12}$	NA	$20x10^{12}$
Critical breakdown field (MV/cm)	0.3	0.4	0.5	2	3.3
Thermal conductivity (W/cm-K)	1.5	0.5	0.7	4.5	>1.7
Relative dielectric constant (εr)	11.8	12.8	12.5	10	9.0

$$P_{max} \propto E_g^4$$

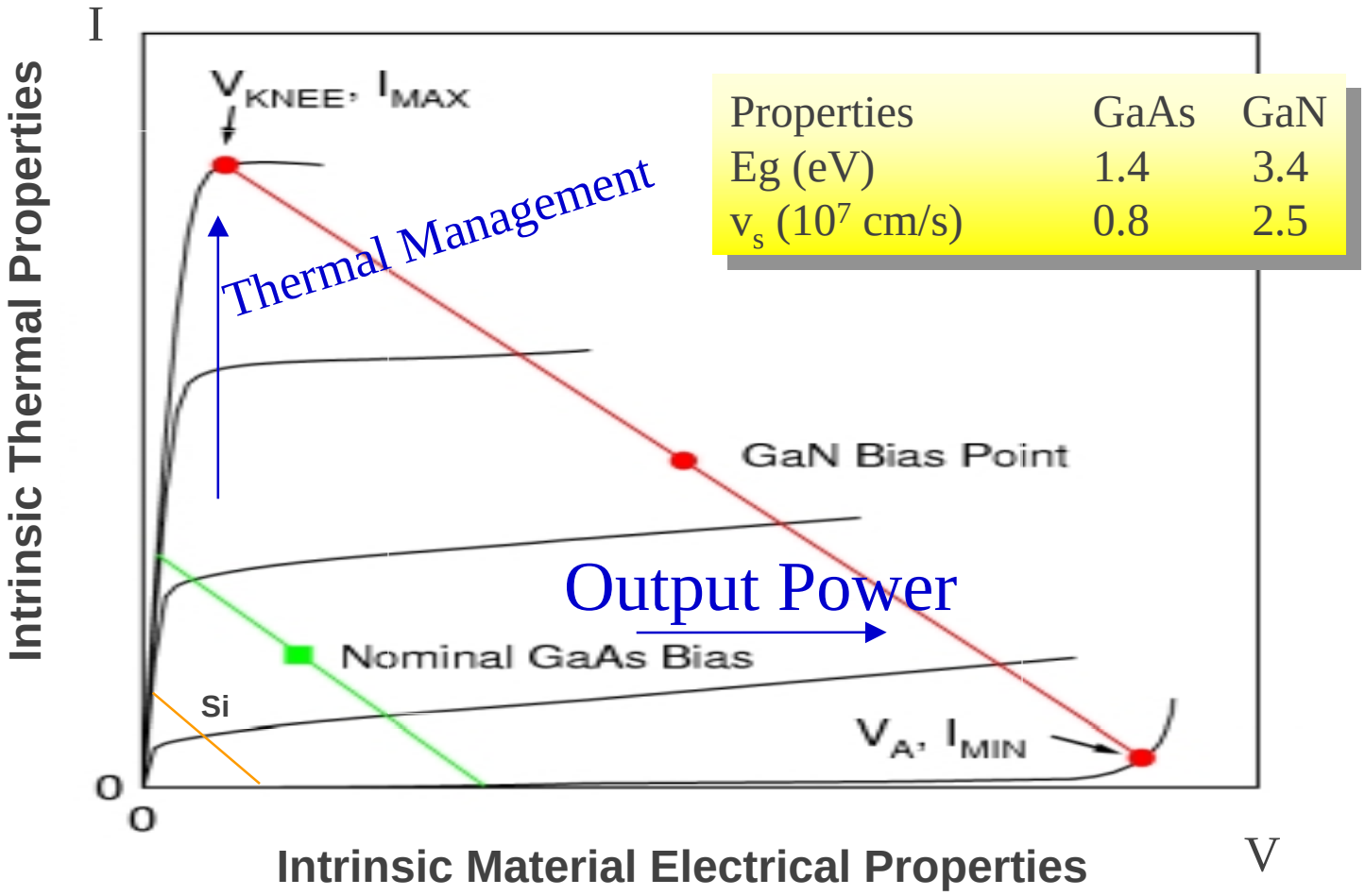
Silicon cannot provide the power-bandwidth product for military applications

III-N Material Challenges

- **Substrates difficult to produce**
- **High temperature material growth process**
- **Defect rampant**
- **Low hole mobility**
- **Deep donors and acceptors**

Limitations of Today's Solid-State Devices

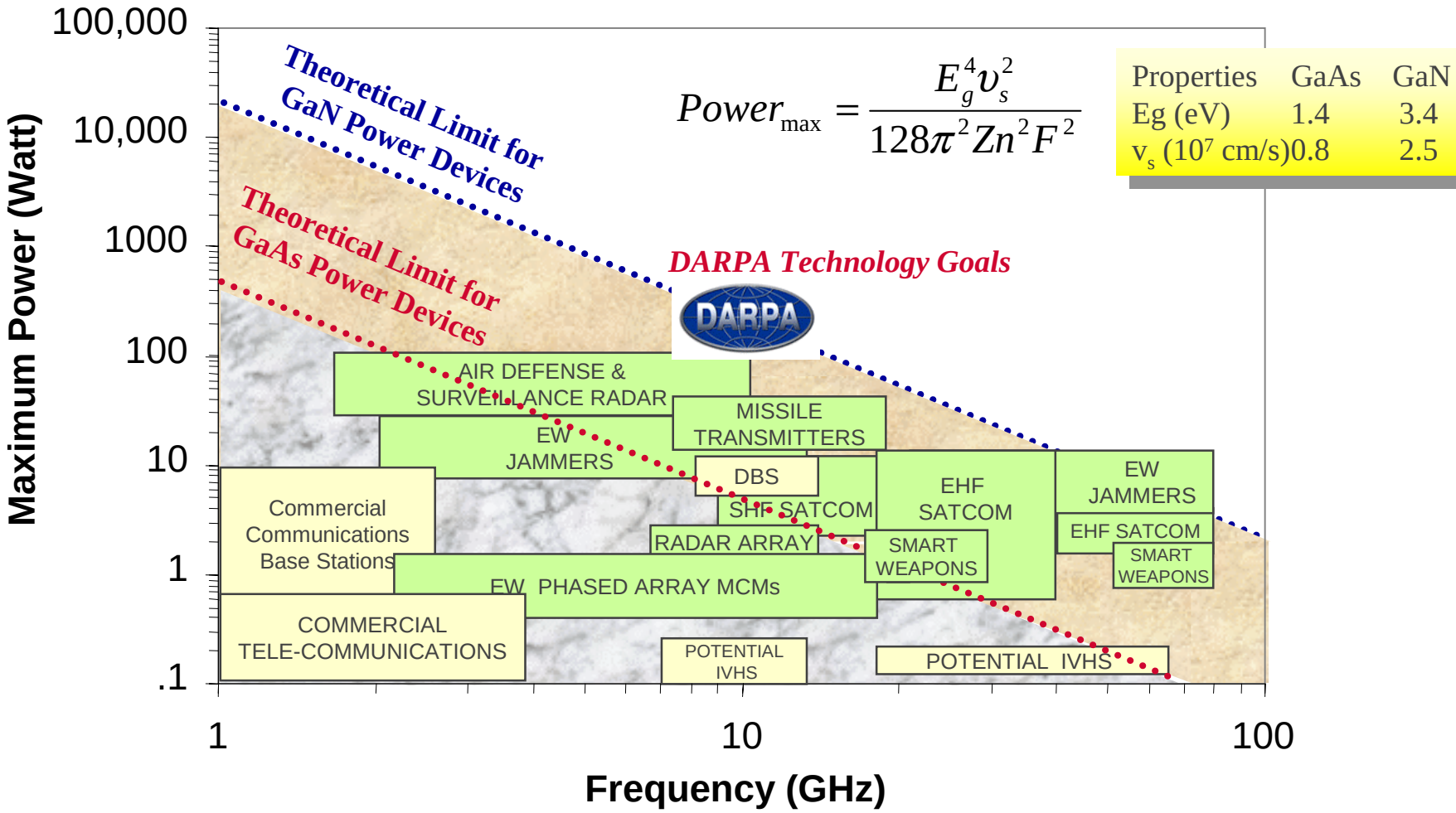
FET Microwave Output Power



Properties	GaAs	GaN
Eg (eV)	1.4	3.4
v_s (10^7 cm/s)	0.8	2.5

$$P_{out} = (\Delta I \times \Delta V)/8$$

Current Technology Limitations and Potential Improvements

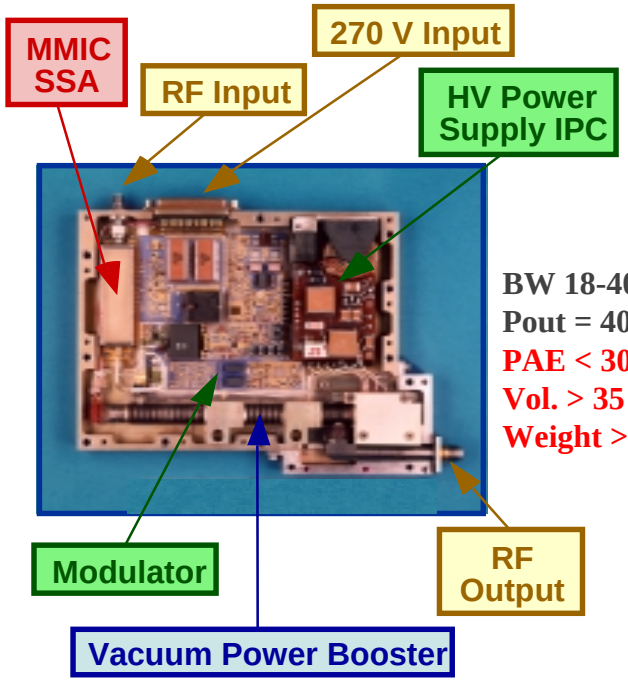


$$Power_{\max} = \frac{E_g^4 v_s^2}{128\pi^2 Z n^2 F^2}$$

Properties	GaAs	GaN
Eg (eV)	1.4	3.4
v_s (10^7 cm/s)	0.8	2.5

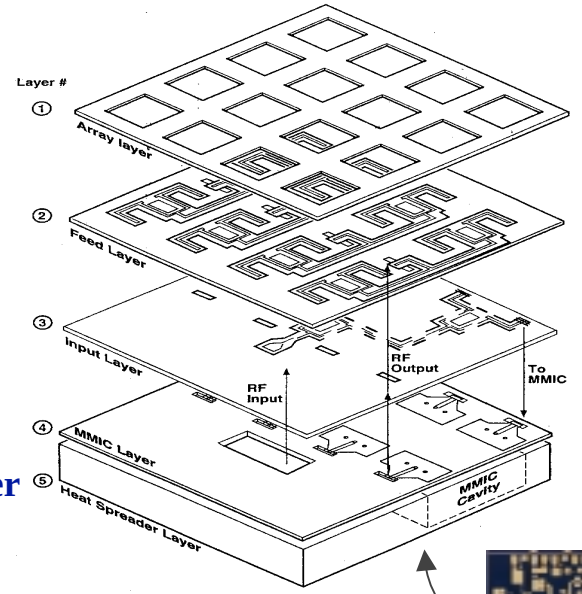
GaN - A Disruptive Technology

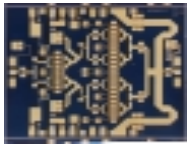
State-of-the-art Microwave Power Module



BW 18-40 GHz
Pout = 40 Watts CW
PAE < 30%
Vol. > 35 cu in.
Weight > 3 lbs

Future RF Single Power Chip in an Advanced Package





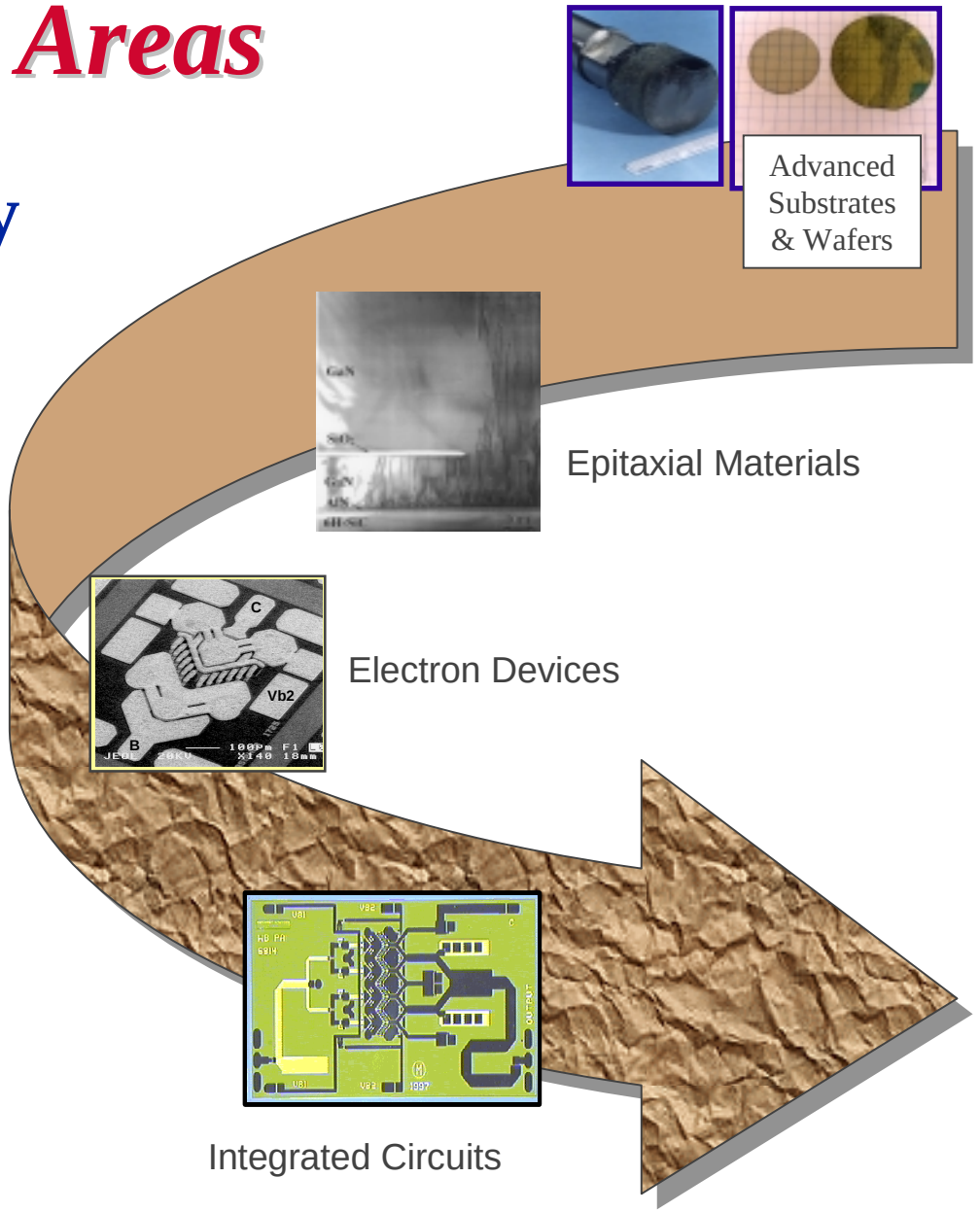
GaN PAmp

- 10X to 100X output power
- Multi-octave bandwidth operation
- >35X reduction in volume
- >50X reduction in weight

High power chips replace heavy and bulky RF power combiners and Microwave Power Modules

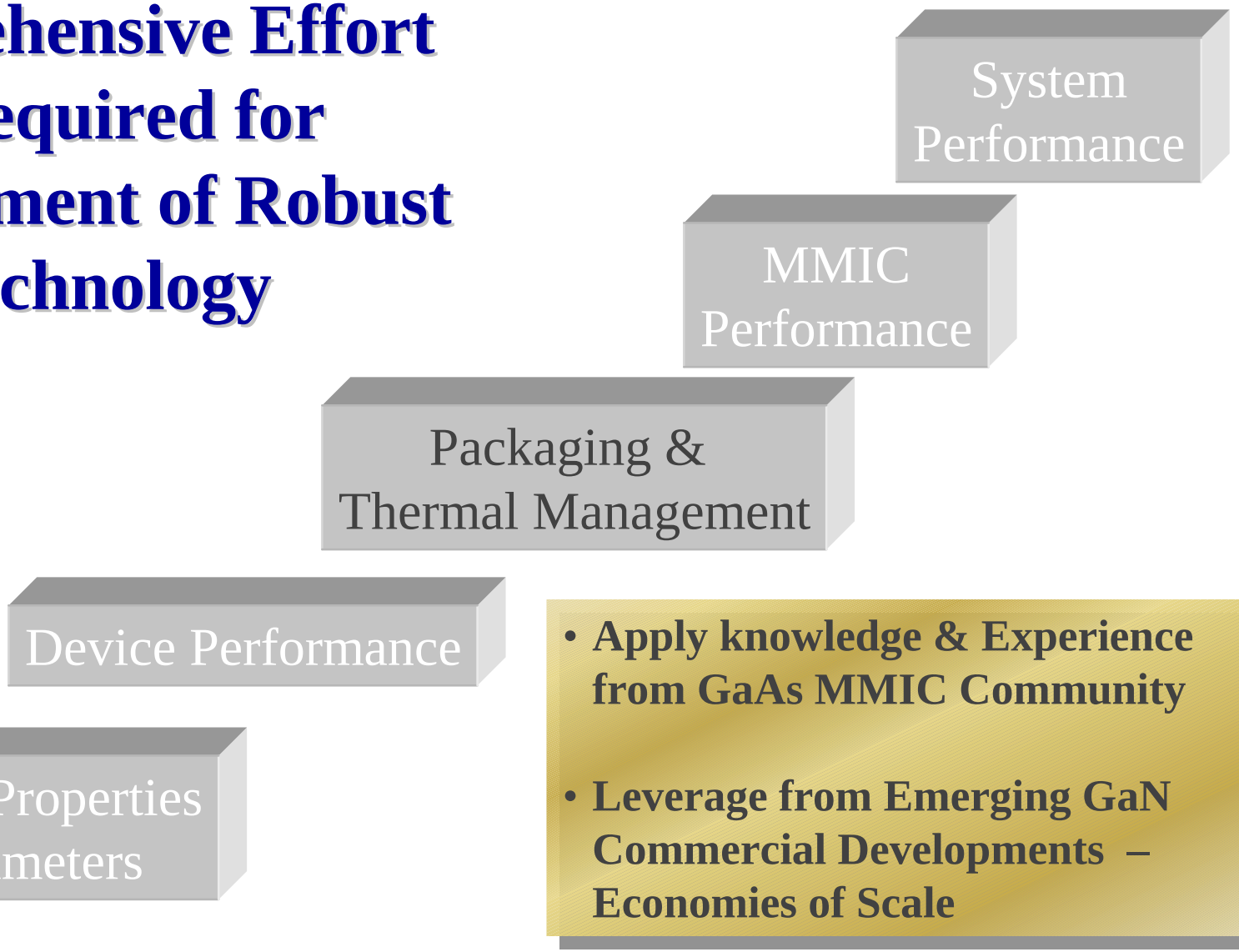
WBG Compound Semiconductors Focus Areas

- **Material Technology**
  - **Bulk Crystal**
  - **Epitaxial Materials**
- **Device Technology**
- **Thermal Control & Packages**



Technical Strategy

Comprehensive Effort is Required for Development of Robust Technology



- **Apply knowledge & Experience from GaAs MMIC Community**
- **Leverage from Emerging GaN Commercial Developments – Economies of Scale**

MTO

DARPA

Military Applications

Multifunction RF Systems

Radar

Electronic Surveillance

High Speed Communications

Electronic Warfare

Smart Weapons

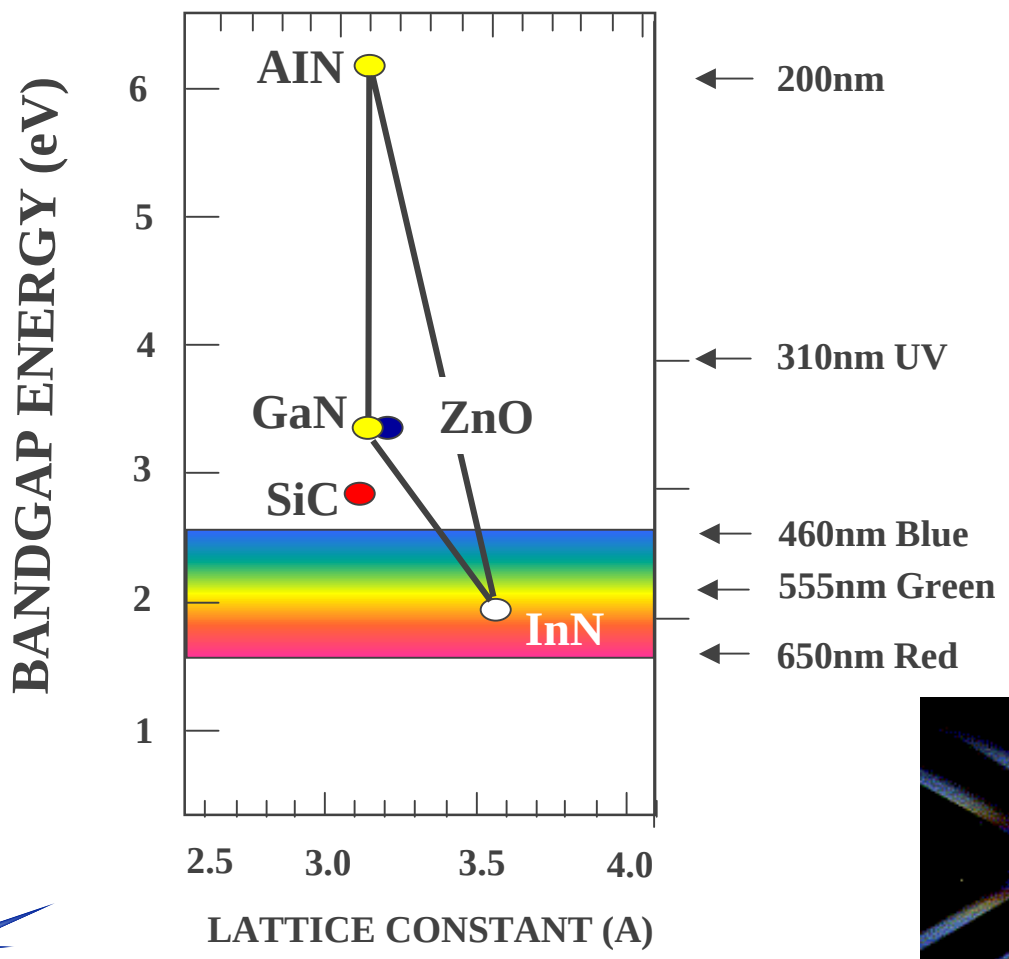
System Benefits

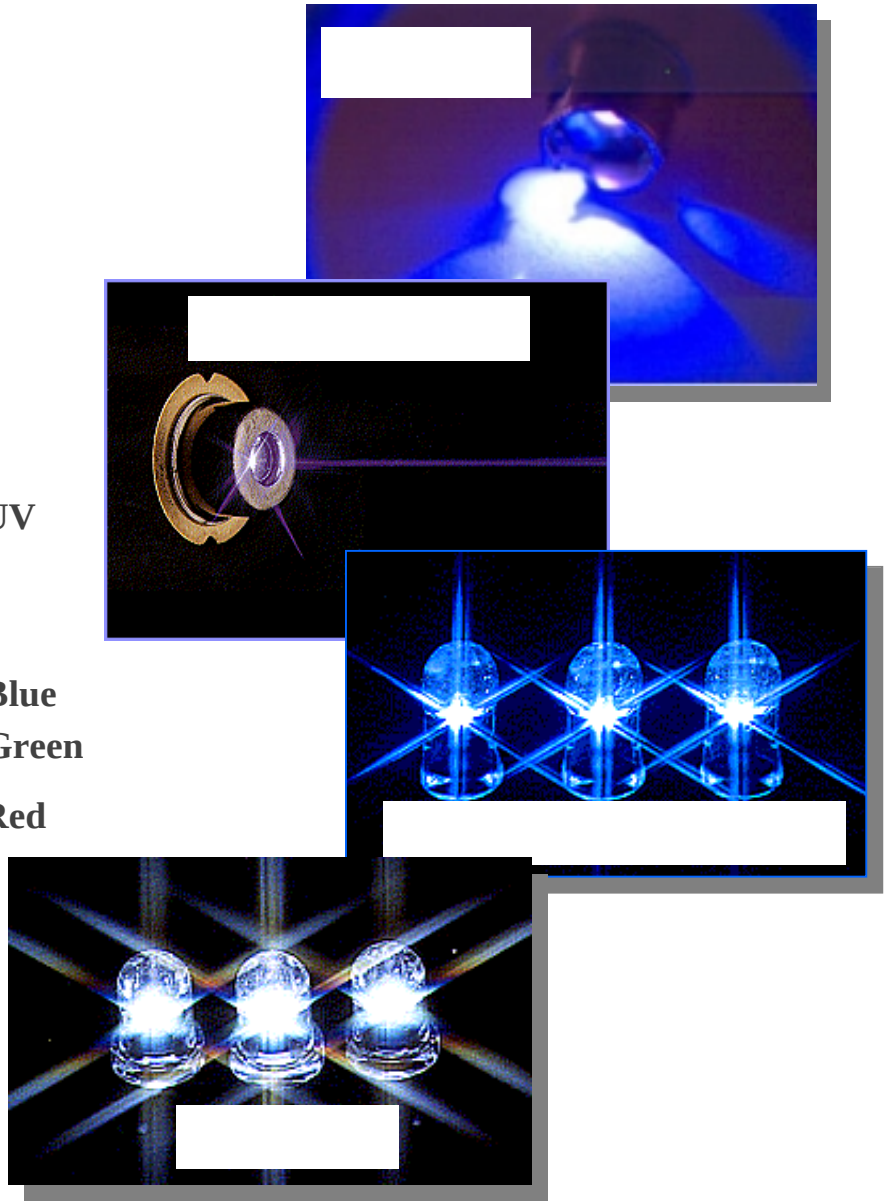
Maximizes bandwidth utilization for multifunctionality

Ability to track targets in heavy clutter or in the presence of enemy jamming

Reduced system size, cooling requirements, and cost

WBG Semiconductors' Optical Benefits

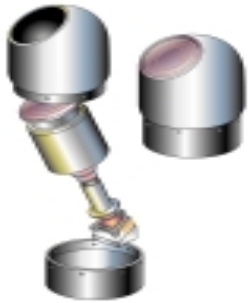




UV Solar Blind Detectors & Current and Future Missile Warning Systems

- Ground vehicle self protection
- Airborne missile threat warning
  - AAA/MG detection and estimation
  - UV search and track
- Biological agent detection
- Engine monitoring
- Combustion control

AN/AAR-47 Ultraviolet
Helos Transports

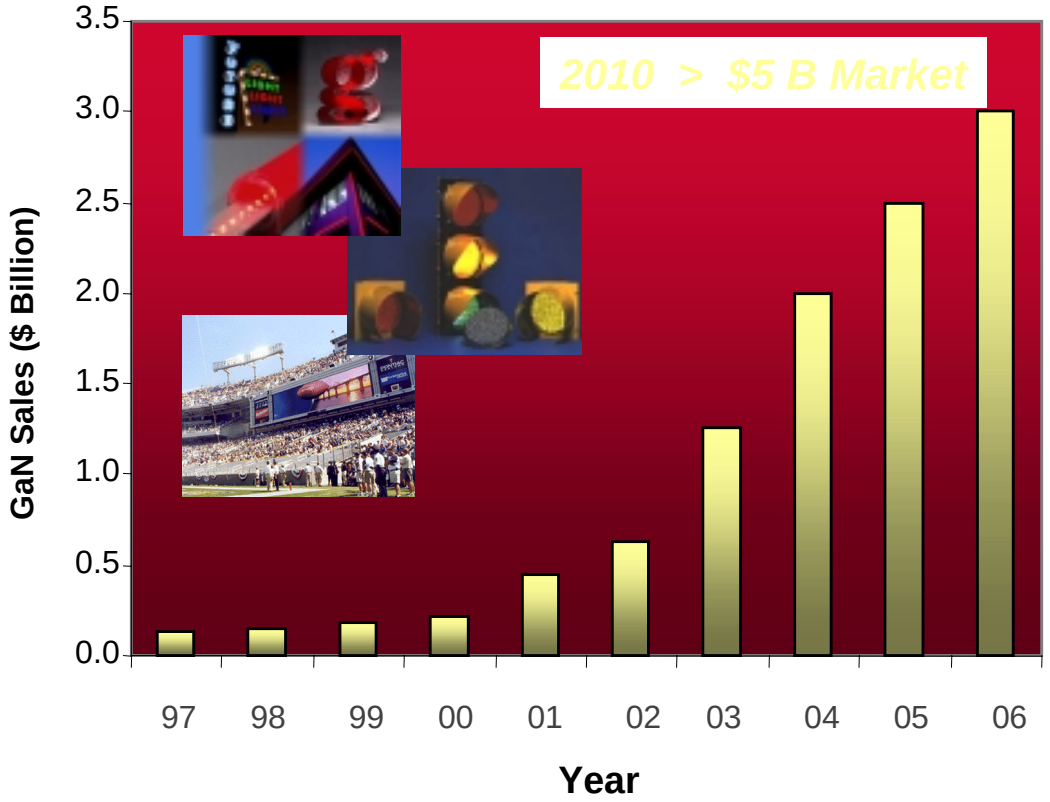


AN/AAR-57
Ultraviolet
Helos Transports
Tactical

Today's Technology
Bulky, Fragile and Expensive

Commercial Opportunities for GaN

- Traffic lights
- Illumination
- Automotive
- Medicine
- Outdoor displays
- Mass data storage
- Wireless communications



Data Source: Strategies Unlimited 1997

The military requirements drive analog and UV detector applications
The commercial opportunities drive optoelectronic applications

Summary

- GaN enabling technology for many military applications
- Many material and device challenges
- Technical strategy requires comprehensive development efforts with many industry and academia partnerships
- Significant system benefits anticipated
- Commercial interest will not meet military needs

DARPA is in the process of creating new opportunities with WBG semiconductors